Charm Hadron Production Fractions

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Abstract

The world average values for the probabilities that a charm quark fragments into D^{*+} and D_s^+ have been calculated to be $f(c \to D^{*+}) = 0.235 \pm 0.007$ (± 0.007) and $f(c \to D_s^+) = 0.101 \pm 0.009$ (± 0.025), respectively. The average values for D^0, D^+ and Λ_c^+ have been also calculated.

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Introduction

The probabilities that a charm quark fragments into D^{*+}, D_s^+ and other charm hadrons are not calculable in perturbative QCD. To obtain them one can use data on charm production in e^+e^- annihilations. The most comprehensive charm measurements were performed by the CLEO [1, 2] and ARGUS [3, 4, 5] collaborations at centre-of-mass energies of about 10 GeV and by the OPAL [6, 7], ALEPH [8] and DELPHI [9, 10] collaborations in Z^0 decays. We will use their measurements performed with charm hadrons reconstructed in the following decay modes[1]:

$$D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow (K^- \pi^+) \pi_s^+, \tag{1}$$

$$D_s^+ \rightarrow \phi \pi^+ \rightarrow (K^- K^+) \pi^+, \tag{2}$$

$$D^0 \rightarrow K^- \pi^+, \tag{3}$$

$$D^+ \rightarrow K^- \pi^+ \pi^+, \tag{4}$$

$$\Lambda_c^+ \rightarrow p K^- \pi^+, \tag{5}$$

The Particle Data Group (PDG) branching ratios for the reference decay modes are [11]: $B(D^{*+}\rightarrow D^0\pi^+) = 0.683 \pm 0.014$, $B(D_s^+\rightarrow \phi\pi^+) = 0.036 \pm 0.009$, $B(D^0\rightarrow K^-\pi^+) = 0.0385 \pm 0.0009$, $B(D^+\rightarrow K^-\pi^+\pi^+) = 0.090 \pm 0.006$ and $B(\Lambda_c^+\rightarrow pK^-\pi^+) = 0.050 \pm 0.013$.

CLEO and ARGUS Measurements

CLEO and ARGUS measurements are summarized in table 1. In the case if two errors are quoted then the first error is statistical and the second is systematic. The D_s^+ production cross sections are corrected for the branching ratio $\mathrm{B}(\phi \rightarrow K^-K^+) = 0.491 \pm 0.008$ [11].

Particle	CLEO $\sigma \cdot B$ (pb)	ARGUS $\sigma \cdot B$ (pb)
D^{*+}	$17.0 \pm 1.5 \pm 1.4$	$14.1 \pm 1.5 \pm 1.4$
D_s^+	$7.2 \pm 1.9 \pm 1.0$	$7.5 \pm 0.8 \pm 0.7$
D^0	$52 \pm 5 \pm 4$	43.8 ± 5.6
D^+	$51 \pm 7 \pm 2$	50.0 ± 6.9
Λ_c^+	$10.0 \pm 1.5 \pm 1.5$	$9.0 \pm 1.2 \pm 1.0$

Table 1: Measured cross sections times branching ratios, $\sigma \cdot B$, for the production of the charm hadrons detected through the reference decay modes at centre-of-mass energies of about 10 GeV.

The total hadronic cross section at 10.55 GeV was measured to be $3.33 \pm 0.05 \pm 0.21$ nb [12]. In Ref. [1] the fraction of $c\bar{c}$ in the total hadronic cross section

[1]The charge conjugated processes are also included.

was estimated with a Monte Carlo calculation to be 0.37 ± 0.02 (syst.) and thus the total cross section into charm particles was calculated to be

$$\sigma(c) = 2.46 \pm 0.04(stat.) \pm 0.20(syst.)\, nb \; . \tag{6}$$

Dividing the measured values from table 1 by the total charm cross section and the branching ratio for the reconstruction mode, charm hadron production fractions have been obtained.

LEP Measurements

LEP measurements of the production rates of D^0, D^+, D^{*+} and Λ_c^+ hadrons in Z^0 decays are summarized in table 2. The OPAL collaboration combined the decay channel $D_s^+ \to \bar{K}^{*0}K^+$ and the channel (2) with the ratio fixed to the PDG ratio of branching fractions [11]: $\mathrm{B}(D_s^+ \to \bar{K}^{*0}K^+)/\mathrm{B}(D_s^+ \to \phi\pi^+) = 0.95 \pm 0.10$. The result is expressed in terms of $\mathrm{B}(D_s^+ \to \phi\pi^+)$ and the uncertainty in this ratio is treated as a systematic error. All D_s^+ product branching ratios in table 2 are corrected for the branching ratio $\mathrm{B}(\phi \to K^-K^+)$.

Particle	OPAL $\frac{\Gamma_{c\bar{c}}}{\Gamma_{had}} \cdot f(c{\to}D,\Lambda) \cdot B$ (%)	ALEPH $\frac{\Gamma_{c\bar{c}}}{\Gamma_{had}} \cdot f(c{\to}D,\Lambda) \cdot B$ (%)	DELPHI $\frac{\Gamma_{c\bar{c}}}{\Gamma_{had}} \cdot f(c{\to}D,\Lambda) \cdot B$ (%)
D_s^+	$0.056 \pm 0.015 \pm 0.007$	$0.072 \pm 0.012 \pm 0.004$	$0.076 \pm 0.007 \pm 0.007$
D^0	$0.389 \pm 0.027\ ^{+0.026}_{-0.024}$	$0.370 \pm 0.011 \pm 0.023$	$0.360 \pm 0.010 \pm 0.021$
D^+	$0.358 \pm 0.046\ ^{+0.025}_{-0.031}$	$0.368 \pm 0.012 \pm 0.020$	$0.349 \pm 0.012 \pm 0.021$
Λ_c^+	$0.041 \pm 0.019 \pm 0.007$	$0.067 \pm 0.007 \pm 0.004$	$0.074 \pm 0.015 \pm 0.009$

Table 2: LEP measurements of the products of the partial decay width of the Z^0 into $c\bar{c}$ quark pairs, $\frac{\Gamma_{c\bar{c}}}{\Gamma_{had}}$, charm hadron production fractions, $f(c \to D, \Lambda)$, and corresponding branching ratios.

Charm hadron production fractions can be obtained dividing the measured products by the branching ratios and the Standard Model value of $\frac{\Gamma_{c\bar{c}}}{\Gamma_{had}}$ [13]:

$$\frac{\Gamma_{c\bar{c}}}{\Gamma_{had}} = 0.1719 \pm 0.0017 \; . \tag{7}$$

There are four LEP measurements which can be used for the $f(c \to D^{*+})$ calculation. The OPAL collaboration has done a double tagged measurement of $f(c \to D^{*+}) \cdot B(D^{*+}{\to}D^0\pi^+)$ [6]. Using $B(D^{*+}{\to}D^0\pi^+) = 0.683$ [11] they have obtained:

$$f(c \to D^{*+}) = 0.222 \pm 0.014 \pm 0.014 \; . \tag{8}$$

Another double tagged measurement has been done by the DELPHI collaboration [10]:

$$f(c \to D^{*+}) \cdot B(D^{*+}{\to}D^0\pi^+) = 0.174 \pm 0.010 \pm 0.004 \; , \tag{9}$$

$$f(c \to D^{*+}) = 0.255 \pm 0.015 \pm 0.006 \; . \tag{10}$$

The ALEPH collaboration has done $D^{*\pm}$ rate measurement [8]. Using $B(D^{*+}\to D^0\pi^+)$ and $B(D^0\to K^-\pi^+)$ values from [11] they have obtained:

$$f(c \to D^{*+}) \ = 0.2333 \pm 0.0102 \pm 0.0084 \ . \tag{11}$$

Another $D^{*\pm}$ rate measurement has been done by the OPAL collaboration [6]:

$$\frac{\Gamma_{c\bar{c}}}{\Gamma_{had}} \cdot f(c \to D^{*+}) \cdot B(D^{*+}\to D^0\pi^+) \cdot B(D^0\to K^-\pi^+) = (1.041 \pm 0.020 \pm 0.040) \times 10^{-3} \ . \tag{12}$$

Using PDG branching ratios and the Standard Model value for $\frac{\Gamma_{c\bar{c}}}{\Gamma_{had}}$, the result can be transformed to $f(c \to D^{*+})$ value:

$$f(c \to D^{*+}) \ = 0.2303 \pm 0.0044 \pm 0.0091 \ . \tag{13}$$

Two OPAL's $f(c \to D^{*+})$ measurements are statistically and systematically correlated. To calculate the correlations one can use the result for $\frac{\Gamma_{c\bar{c}}}{\Gamma_{had}}$ obtained by the OPAL collaboration [6] from the measurements (8) and (12):

$$\frac{\Gamma_{c\bar{c}}}{\Gamma_{had}} \ = 0.180 \pm 0.011 \pm 0.012 \ . \tag{14}$$

Note that old value $B(D^0\to K^-\pi^+) = 0.0383$ [14] has been used by the OPAL collaboration for the $\frac{\Gamma_{c\bar{c}}}{\Gamma_{had}}$ calculation.

Average Charm Hadron Rates

Tables 3 and 4 contain all charm hadron production fractions discussed above and their average values. In the case if two errors are quoted then the first error is statistical and the second is systematic. The errors in parentheses for the average values are due to the uncertainties in the charm hadron branching ratios. They can be ignored in the case if the values are used for comparisons to measurements done with the same decay mode and the same branching ratio for the mode.

	$f(c \to D^0)$ (%)	$f(c \to D^+)$ (%)	$f(c \to \Lambda_c^+)$ (%)
CLEO	$54.9 \pm 5.4 \pm 6.1$	$23.0 \pm 3.2 \pm 2.1$	$8.1 \pm 1.2 \pm 1.4$
ARGUS	46.2 ± 7.0	22.6 ± 3.6	$7.3 \pm 1.0 \pm 1.0$
ALEPH	$55.9 \pm 1.7 \pm 3.5$	$23.8 \pm 0.8 \pm 1.3$	$7.8 \pm 0.8 \pm 0.4$
DELPHI	$54.4 \pm 1.5 \pm 3.2$	$22.6 \pm 0.8 \pm 1.4$	$8.6 \pm 1.8 \pm 1.0$
OPAL	$58.8 \pm 4.1 {}^{+4.0}_{-3.7}$	$23.1 \pm 3.0 {}^{+1.6}_{-2.0}$	$4.8 \pm 2.2 \pm 0.8$
Average	54.9 ± 2.3 (± 1.3)	23.2 ± 1.0 (± 1.5)	7.6 ± 0.7 (± 2.0)

Table 3: Measured and average probabilities that a charm quark fragments into D^0, D^+ and Λ_c^+. The average probabilitity errors in parentheses are due to the uncertainties in the charm hadron branching ratios.

To average the measurements a standard weighted least-squares procedure has been used [11]. In the case if statistical and systematic errors were quoted separately they have

	$f(c \to D_s^+)$ (%)	$f(c \to D^{*+})$ (%)
CLEO	8.1 ± 2.2 ± 1.3	26.3 ± 2.4 ± 3.0
ARGUS	8.5 ± 0.9 ± 1.0	21.8 ± 2.3 ± 2.8
ALEPH	11.5 ± 1.9 ± 0.7	23.3 ± 1.0 ± 0.8
DELPHI	12.4 ± 1.1 ± 1.2	25.5 ± 1.5 ± 0.6
OPAL	9.0 ± 2.4 ± 1.1	22.2 ± 1.4 ± 1.4
		23.0 ± 0.4 ± 0.9
Average	10.1 ± 0.9 (± 2.5)	23.5 ± 0.7 (± 0.7)

Table 4: Measured and average probabilities that a charm quark fragments into D_s^+ and D^{*+}. The average probabilitity errors in parentheses are due to the uncertainties in the charm hadron branching ratios.

been added in quadrature and the combined error has been used. The OPAL collaboration quoted asymmetric systematic errors for D^0 and D^+ measurements. The errors with larger absolute values have been used for averages in these two cases.

The average takes into account:

- common ARGUS/CLEO errors due to the errors in the total charm cross sections (6);
- common LEP errors due to the error in the Standard Model value of $\frac{\Gamma_{c\bar{c}}}{\Gamma_{had}}$(7);
- correlations between two OPAL's $f(c \to D^{*+})$ measurements.

Other experimental errors were assumed to be uncorrelated.

A sum of the average D^0, D^+, D_s^+ and Λ_c^+ production fractions equals to 95.8% leaving a room for the fragmentation of a charm quark to Ξ_c and Ω_c.

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